

# Application of artificial neural networks for agent-based simulation of emergency evacuation from buildings for various purpose

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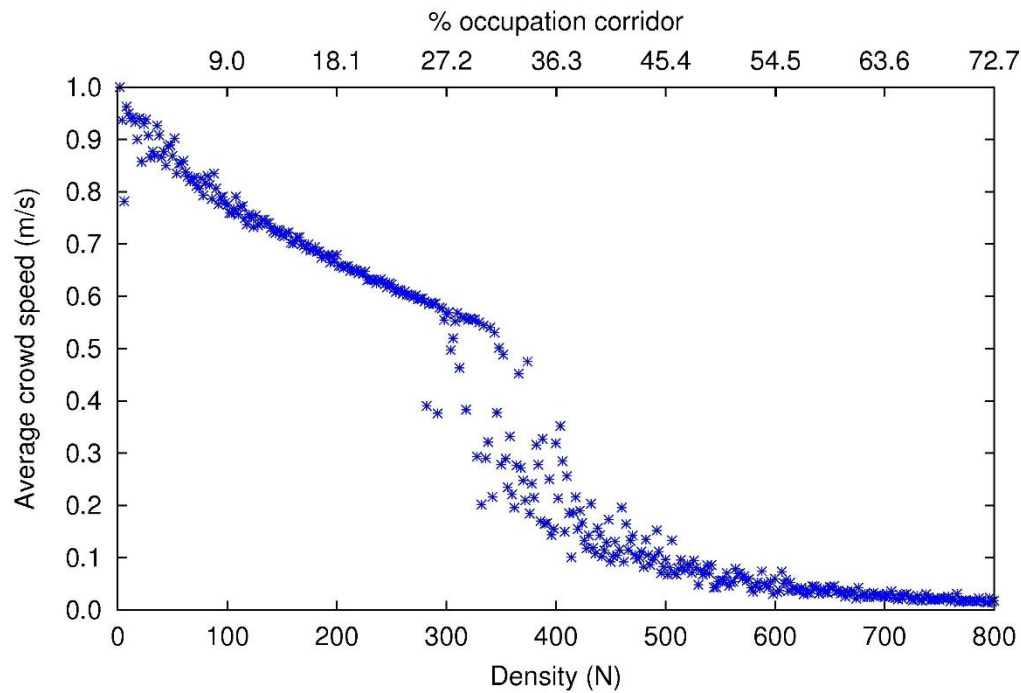
**Abstract.** The application of Artificial Neural Networks (ANN) for the pedestrian flow simulation is a new stage in the development of system simulation, which has become accessible due to the exponential growth of computing power. Authors, together with colleagues from the Beihang University, Beijing, developed a program that allows to solve practical problems connected with emergency evacuation in construction using system simulation based on ANN. Machine learning allows us to precisely simulate the behavior of all people during evacuation, their reaction on obstacles and other people, and predict the load on the main evacuation routes in advance and, as a consequence, make changes to the plans of the buildings, where necessary. With the help of this program architects and designers can find the right solutions for the projects, which will not require any further adjustments, after the building will be constructed. This program is especially important for unique multifunctional facilities, for example, sports stadiums or shopping and entertainment centers, where a real evacuation check cannot be carried out.

## 1. Introduction

Currently, there are many methods for simulating a pedestrian flow, which are taking into account the characteristics of people's behavior in extreme situations [1], [2]. Depending on the task for evacuating people from buildings, one of the existing methods of simulation can be chosen, but due to the fact that space-planning decisions of buildings, especially multifunctional ones, are becoming more complex, it is necessary to develop new methods. With the growth of computing power in the 21st century, a new method of simulation with the use of deep machine learning is now available. Today, there are two main directions in the simulation of the pedestrian flow: macroscopic and microscopic.

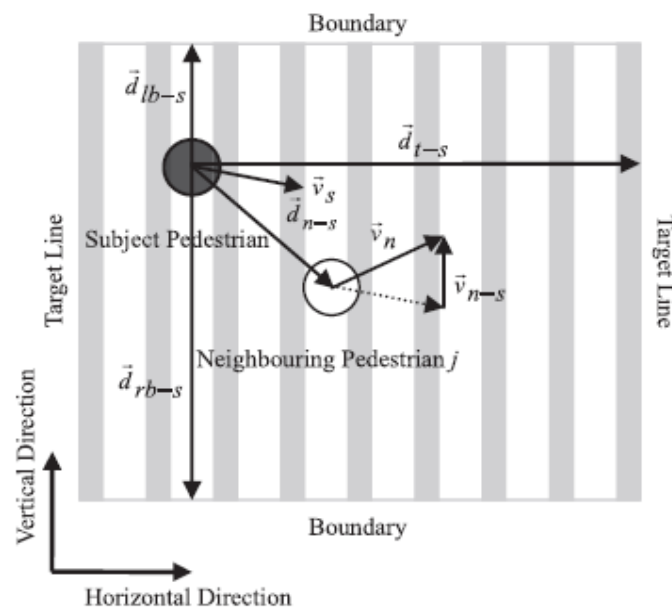
The macroscopic models convert the scenario into a node-link presentation (figure.1) and focus on determining movement time [3], [4]. These models are rapid tools that provide an overview of the movement but are unable to describe the movement patterns in different areas at different time steps.





**Figure 1.** Average speed vs. density

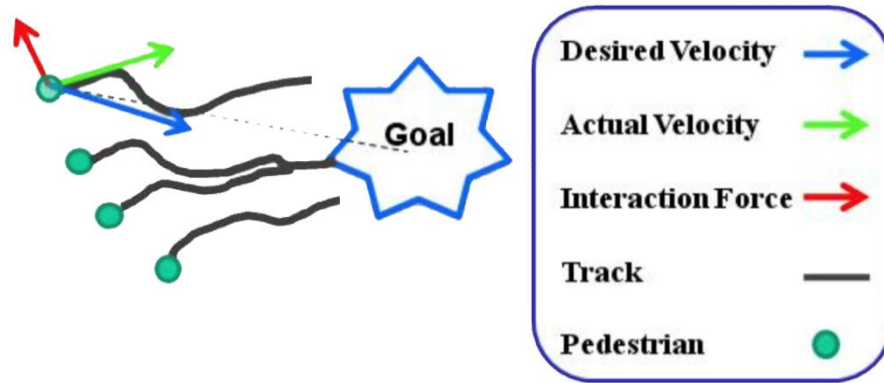
The microscopic models provide more detail by imposing the rules of movement onto each agent and letting them interact to simulate pedestrian movement figure 2.



**Figure 2.** Typical interaction patterns between subject pedestrian and various environmental stimuli in pedestrian movement on a crosswalk

Thus, bottleneck areas in crowded public traffic spots can be predicted and facilities optimized to alleviate congestion. Currently, popular microscopic models are categorized into force- and agent-

based models based on the ways in which the pedestrians are represented and propelled [5]. One representative force-based model is the Social Force (SF) model [6], in which Newton's Law of Motion is introduced to represent the interaction between pedestrians and obstacles. Pedestrian movement in continuous space is determined by the resultant force experienced by the pedestrian. In the respect of affected entity, social force can be presented as combination of: desired velocity, actual velocity and interaction force figure 3.



**Figure 3.** Elements of Social Force Model

Mathematically SF model can be described by 3 equations:

- Langevin equation:

$$m_i \frac{dv_i}{dt_i} = m_i \frac{v_i^0(t)e_i^0(t) - v_i(t)}{\tau_i} + \sum_{j(\neq i)} f_{ij} + \sum_W f_{iW} \quad (1)$$

- Interaction Force between pedestrians

$$f_{ij} = \left\{ A_i \exp\left[\left(r_{ij} - d_{ij}\right) / B_j\right] + kg\left(r_{ij} - d_{ij}\right) \right\} n_{ij} + \kappa g\left(r_{ij} - d_{ij}\right) \Delta v_{ji}^t t_{ij} \quad (2)$$

- Interaction Force between pedestrian and obstacles

$$f_{iW} = \left\{ A_i \exp\left[\left(r_i - d_{iW}\right) / B_i\right] + kg\left(r_i - d_{iW}\right) \right\} n_{iW} - \kappa g\left(r_i - d_{iW}\right) (v_i t_i) t_{iW} \quad (3)$$

However, in this case, the simulation of the motion is given only by formulas, and as a result, the movement of each object becomes too mechanical and does not resemble a real pedestrian.

In contrast to the SF model, in the agent-based models, each pedestrian is usually represented as an independent and autonomous entity capable of adaptation. On the basis of the agent-based model, we have developed an improved principle of simulation in which each pedestrian is not just an independent unit (agent) with its desired goal and track, but constantly reacts on the environment and behavior of other participants in the flow in the way that real people reacts.

The proposed principle of simulation can be applied in various situations due to its ability to simulate the unique behavior of each participant of the flow. The utility maximization approach is used to navigate the pedestrian's moving direction. The pedestrians adjust their moving speed in the moving direction in terms of the perceived environmental information [7].

To test the model author have simulated various standard scenarios, which are commonly used for pedestrian flow simulations: unidirectional, counter, crossing and bottleneck flows [8],[9],[10] and to interpret various pedestrian collective behavior and self-organized phenomena such as arching in front of a congested doorway, faster-is-slower evacuation [11], [12], lane formation in counterflow conditions [13], strip formation in crossing-flow conditions [14] and oscillation in counterflow through a bottleneck passage [15].

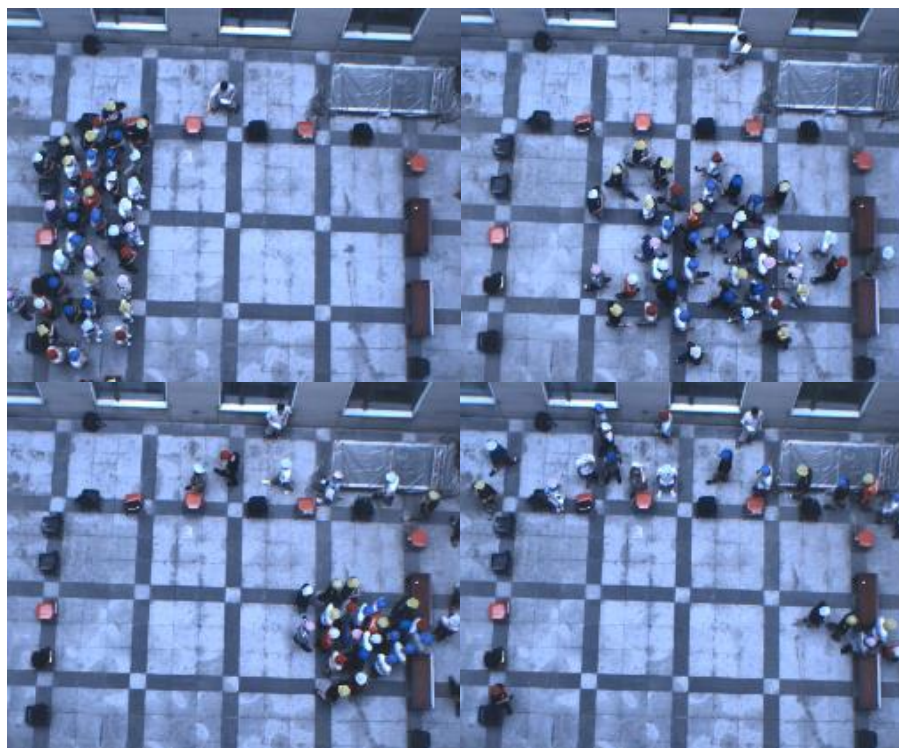
Working on the project together with Chinese scientists from Beihang university, we have noticed that in the practice of designing construction projects in Russia, programs for simulation of evacuation from buildings of various functional purposes has not yet been used. But when it comes to the speed of emergency evacuation, on which people's lives depend, such a program is a must and it should provide maximum accuracy, so the discrepancy between a real human behaviour and virtual is minimal.

## 2. Simulation of evacuation

Simulation of evacuation allows to predict the load on evacuation routes and, possibly, to prevent situations when people might be in danger. Conducting a test evacuation in real conditions is almost impossible, as, first, the completion of all construction work in the building is required and, secondly, it is expensive and time-consuming. However, with the development of simulation programs, the task becomes much easier. These programs are especially important for unique multifunctional facilities, for example, sports stadiums or shopping and entertainment centers, where a real evacuation check cannot be carried out.

Our main aim was to simulate emergency evacuation from the building, based on the already existing data and the behavior of people in a real evacuation. Therefore, at the first stage, we developed a program for processing real evacuation data, built on a neural network.

For the initial training of a neural network and obtaining information on real human behavior during evacuation, evacuation experiments were conducted in small spaces with various obstacles and different widths of evacuation exits figure 4.

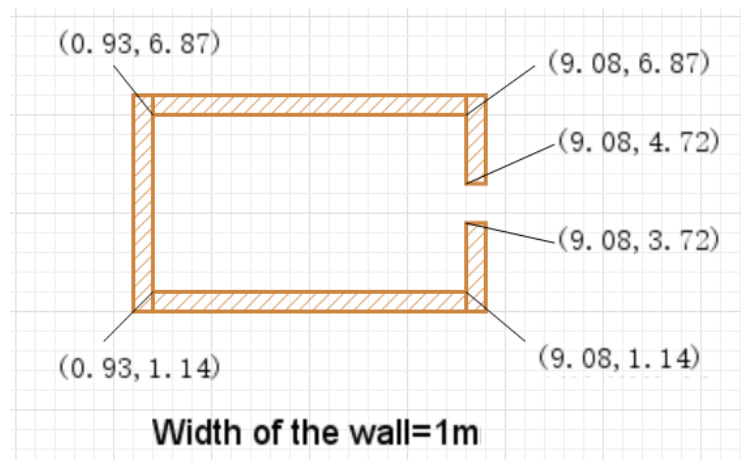


**Figure 4.** Example of recorded experiments

After recording the experiment on the video and processing it, we received information on the movement of each participant and formed a table 1, where  $No(x)$  is a single participant in the motion. Each line indicates a trajectory for one pedestrian, while each column represents the position of all pedestrians inside the map, figure 5, at a specific time.

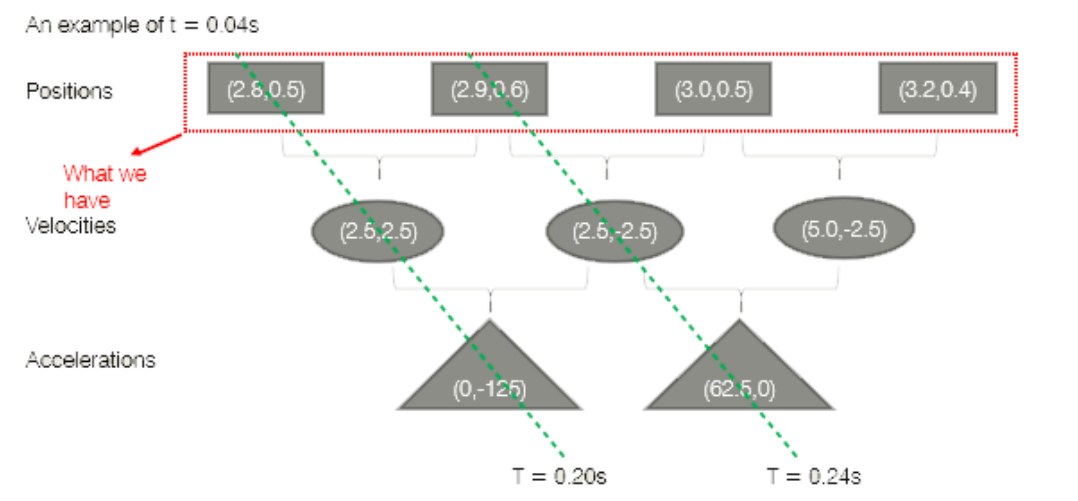
**Table 1.** Position of all pedestrians every  $t=0.04s$  time step

|             | $t=0.04s$  | $t=0.08s$  | $t=0.12s$ |
|-------------|------------|------------|-----------|
| <b>No.1</b> | (2.8, 0.4) | (2.9, 0.5) | ...       |
| <b>No.2</b> | (3.6, 0.9) | (3.9, 1.1) | ...       |
| <b>No.3</b> | ...        | ...        | ...       |

**Figure 5.** Simplified experiment map

### 3. Data processing for training neural network

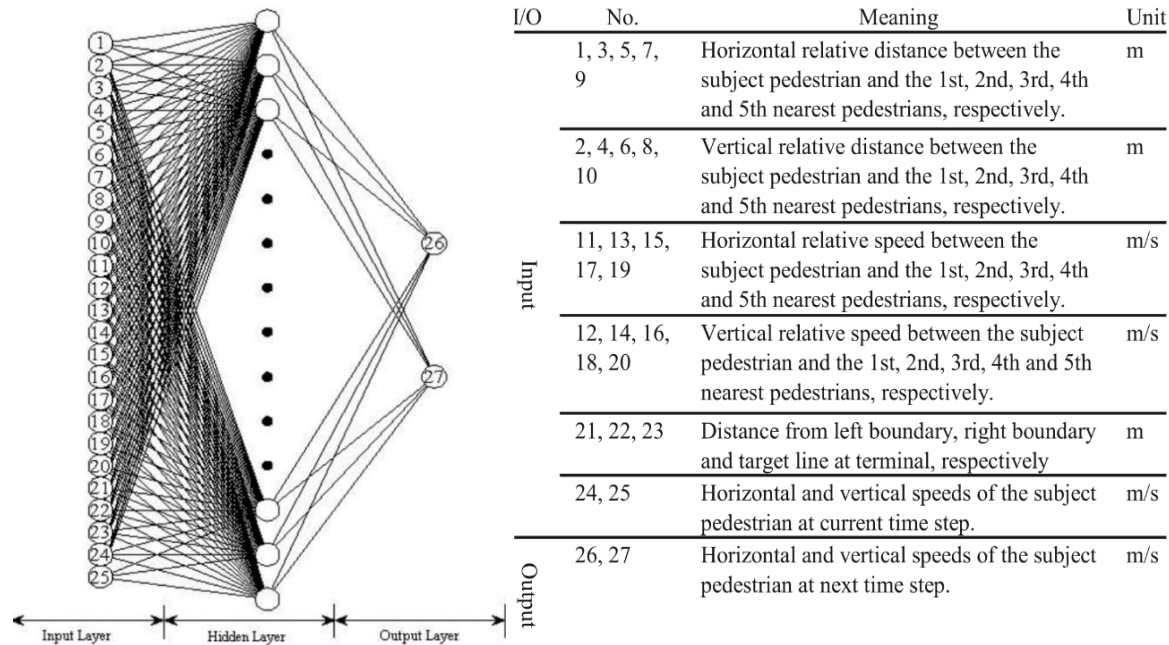
By mathematical analysis of the obtained coordinates, we find out the velocities and accelerations of each pedestrian at each moment of time figure 6.

**Figure 6.** Example of obtaining velocities and accelerations at  $t=0.04s$ 

Using an artificial neural network (ANN) approach to simulate pedestrian traffic, we apply a deep neural network with several hidden layers and dropouts and get vertical and horizontal velocities in the



next step of time at the output, in other words, our neural network predicts human behavior at any time and completely simulates his behavior depending on the surrounding situation (Fig. 6).



**Figure 7.** Input and Output of the developed ANN

We have used "Python Tensorflow + Numpy" to create and train a neural network and "Java DL4j + Nd4j" to create visualization and use the trained neural network to simulate other evacuations. In order to verify the correctness of the training of our neural network, we simulated the initial evacuation and see how pedestrians moved on the video and how they move in the simulation. We obtained similar results.

#### 4. Conclusion

Innovativeness of the program developed by authors lies in the ability to simulate evacuation from buildings for various purposes with high accuracy due to ability to learn from the data of existing evacuations. This allows us to predict the load on the evacuation routes in advance and, as a result, make changes in the plans of the buildings, where necessary. In the long run this saves time and money for developers, because they can find the right solutions for the projects, which will not require any further adjustments, after the building will be constructed.

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